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9500 GILMAN DRIVE
LA JOLLA, CALIFORNIA 92093-0209
PHONE: (619) 534-4333
FAX: (619) 534-0300

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Scientific Officer Code: 1121CS
Alan Brandt
Office of Naval Research
800 North Quincy Street
Arlington, VA 22217-5000

Attn: Ms. Janet Meyers
Procurement Technician
Office of Naval Research
San Diego Regional Office
4520 Executive Drive, Suite 300
San Diego, CA 92121-3019

Director, Naval Research Laboratory
Attn: Code 2627
Washington, DC 20375

Defense Technical Information Center
Building 5, Cameron Station
Alexandria, VA 22314

NRE: Grant No.: N00014-89-J-1060
Final Technical Report

Enclosed is a copy of the final technical report for the grant referenced above.

Sincerely,

Judy Keplinger

Judy Keplinger
Administrative Assistant

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Fluid-Granular Boundary Layer Ventilated

DEPARTMENT OF THE NAVY
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SAN DIEGO REGIONAL OFFICE
4520 EXECUTIVE DRIVE, SUITE 300
SAN DIEGO CA 92121-3019

Distribution: Douglas Inman
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Attn: University Closeout Administrator

The contract or grant number listed below has expired. In order to close out this agreement and process final payment, the following documents noted with a "Y" in the REQUIRED column need to be submitted within 60 days. Those indicating and "N" or BLANK are not required.

AGREEMENT NUMBER:	PRINCIPAL INVESTIGATORS LASTNAME:	EXPIRATION DATE:
N00014-89-J-1060	Dr. Douglas Inman	9/30/94

REQUIRED?

[Y] **FINAL TECHNICAL REPORT:** SF298 submitted 12/31/94 - is there also a final technical report?

Final techinical report, performance report, or other deliverable and transmittal document for the report. Documentation furnished must show the date the report was submitted to the Scientific Officer or Program Manager and include a copy of the Standard Form 298 (Report Documentation Page) for DOD programs or as required by the Agreement terms and conditions. A completed Standard Form 298 must be completed and submitted to the Defense Technical Information Center (DTIC) or other location in accordance with the terms of your agreement. (For your convenience, a blank SF-298 is attached for your use)

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Final Voucher, for Contracts, including the Contractor's Release of the Government and Contractor's Assignment of Refunds, Rebates and Credits. If this agreement is a GRANT, a Final Financial Status Report (SF-269) and summary of GRANT costs shall be submitted in lieu of a final voucher. (See your agreement for specific requirements)

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Sincerely,

Robert L. Bachman / for
Ms. Janet Meyers
Procurement Technician

If this agreement is being renewed/extended, please complete the information indicated below and return a copy of this letter to our office. Please include a copy of your proposal forwarding letter. THANK-YOU

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9500 GILMAN DRIVE
LA JOLLA, CALIFORNIA 92093-0209
PHONE: (619) 534-4333
FAX: (619) 534-0300

30 January 1995

Dr. Thomas Kinder
Chief of Naval Research
ONR Code 321CS
800 N. Quincy Rd.
Arlington, VA 22217-5660

Dear Tom:

I am enclosing the final reports for my two ONR-supported grants, "Fluid-Granular Boundary Layers under Nearbreaking Waves" and the combined grants for my Ocean Science Educator Award and the research support for Tom Drake. Also enclosed are two copies of our recent JFM paper, "Ventilated Oscillatory Boundary Layers."

Sincerely,

Doug

Douglas L. Inman
Research Professor of Oceanography

Enclosures

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6. AUTHOR(S)
Douglas L. Inman and Daniel C. Conley

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Center for Coastal Studies, 0209
Scripps Institution of Oceanography, UCSD
9500 Gilman Drive
La Jolla, CA 92093-0209

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Office of Naval Research
Code 1121CS ⟶ 321 CD
800 North Quincy Street, Ballston Tower One
Arlington, VA 22217-5660

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13. ABSTRACT *(Maximum 200 words)*

Field study of the fluid-granular boundary layer under nearbreaking waves showed a pronounced crest-trough asymmetry; with a visually different structural sequence under the crest, referred to as streaking, roiling and pluming. It was suggested that this asymmetry, which results from more intense stress under the crest, was caused by wave-induced ventilation through the porous bed (Conley & Inman, 1992). This contention was supported by analysis of the bedform response to stress asymmetry manifest in the beach profile response to changing wave conditions (Inman et al, 1993).

Recent work has focused on laboratory experiments to determine the magnitude of boundary layer asymmetries due to ventilation as well as the sensitivity of these asymmetries to the ventilation parameter, and wave shape (Conley & Inman, 1993; 1994). This study shows that boundary layer ventilation is an essential element in the stress asymmetry that drives sediment transport by waves, and that leads to the characteristic equilibrium profile under shoaling waves. Ventilation also explains the net onshore transport of sediment over gently sloping profiles as at False Cape on the Outer Banks of North Carolina (Inman & Dolan, 1989).

14. SUBJECT TERMS
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FINAL TECHNICAL REPORT:

FLUID-GRANULAR BOUNDARY LAYERS UNDER NEARBREAKING WAVES

Douglas L. Inman and Daniel C. Conley

The long-term goals of this project were to advance the understanding of fluid-sediment interactions in the boundary layer under waves; and in this way to improve models of the transport of sediment, nutrients and contaminants. Improved modeling will lead to better understanding of bedform response to fluid forcing and to improved prediction of beach morphology.

The study began with a series of field investigations that identified areas of net onshore transport of sediment over gently sloping bottoms (Inman & Dolan, 1989), and a detailed study of beach profiles that indicated that beach stability versus crosshore-transport was governed by the *equilibrium beach profile*. Disequilibrium conditions could lead to onshore or offshore transport (Inman et al, 1993). This emphasized the need for an improved understanding of the oscillatory boundary layer under shoaling waves. Field study of the fluid-granular boundary layer under nearbreaking waves showed a pronounced crest-trough asymmetry; with a visually different structural sequence under the crest, referred to as *streaking, roiling* and *pluming*. Roiling and pluming did not occur under the wave trough. It was suggested that this asymmetry, which results from more intense stress under the crest, was caused by wave-induced ventilation through the porous bed (Conley & Inman, 1992).

Recent work has focused on laboratory experiments to determine the magnitude of boundary layer asymmetries due to ventilation as well as the sensitivity of these asymmetries to the ventilation parameter, and wave shape (Conley & Inman, 1993; 1994). As a result of this research, it has been shown that boundary layer ventilation is an essential element in the stress asymmetry that drives sediment transport by waves, and that leads to the characteristic equilibrium profile under shoaling waves. Ventilation also explains the net onshore transport of sediment over gently sloping profiles as at False Cape on the Outer Banks of North Carolina (Inman & Dolan, 1989).

Ventilated oscillatory boundary layers are those arising over permeable beds when the primary boundary parallel flow is subject to a secondary transpiration flow through the bed. The

transpiration flow is induced by the pressure field of the wave and has the same frequency and shape as the wave form; producing flow into the bed (*suction*) under the wave crest and out of the bed (*injection*) under the wave trough (Figure 1). A flow *ventilation parameter* $\tilde{V}$ is defined as

$$\tilde{V} = w_m / u_m$$

where u_m is the maximum boundary-parallel orbital velocity (positive under the wave crest) and w_m is the maximum vertical velocity into (negative) and out of (positive) the bed, and the sign of $\tilde{V}$ indicates whether injection ($\tilde{V} > 0$) or suction ($\tilde{V} < 0$) occurs concurrently with positive orbital flow. Additionally, an *instantaneous ventilation parameter* is defined as $\tilde{V}' = w(t)/u(t)$.

In general, boundary transpiration modifies the boundary layer velocity profile. Suction pulls streamlines down towards the bed, shifting the velocity profile closer to the bed. This results in high shear near the bed and, therefore, higher shear stress at the bed. Injection raises the streamlines and reduces the stress at the bed. Since the ventilated oscillatory boundary layer experiences both suction and injection in one full cycle, the result is a net stress, $< \tau_V >$, and a net boundary layer velocity, or *ventilation current* $< \vec{u}_V >$, in an otherwise symmetrical flow. The ventilation current is in addition to the well known "bottom wind" which occurs under symmetrical oscillations over an impermeable bed (Longuet-Higgins, 1953).

The maximum shear stress τ_m is a fundamental element in the onset of grain motion under wave action. However, in terms of the beach profile, the net bottom stress is the most important variable in determining where grains will travel. For ventilated beds, the net stress is a consequence of the bed stress reduction due to injection and increase due to suction. This net stress is referred to as the *ventilation stress asymmetry*, $< \tau_V >$, defined as the net time-averaged bottom stress over one complete wave cycle.

The stress asymmetries due to ventilation for symmetrical and asymmetrical waveforms are plotted in dimensionless form in Figure 2. In this figure $< \tau_V >$ is normalized by the average gross unventilated stress during a full cycle, and the solid line is for symmetrical wave forms. It is apparent that this relation fits the data (open O) quite well for $0 > \tilde{V} > -0.01$. Further, a dashed line of the same slope but passing through the ordinate intersect of $<\tau_V>/<|\tau_o|> \simeq 0.2$

appears to provide a satisfactory fit for the data for asymmetrical waveforms (solid ▲). The ordinate intercept is the normalized value of the stress asymmetry due to the waveform alone in the absence of ventilation.

Laboratory study of spherical grains show that ventilation induces a net transport of particles which ranges up to 20% of the unventilated orbital displacement. The tests were performed on groups of identical spheres in bedload motion over a permeable, but otherwise smooth bed in an oscillatory flow tunnel with a particle displacement (orbital diameter) of 2.1 m. The particle groups consisted of cellulose acetate (ρ_s = 1.32 g/cm^3) spheres of diameter 2, 4, 6.5 and 8 mm, and stainless steel (ρ_s = 7.83 g/cm^3) spheres of diameter 2.1 and 6.4 mm. It was found that the net transport falls off rapidly with decreasing value of $|\tilde{V}|$.

The results from this study have profound implications for the study and modeling of sediment transport by waves. Several parameterizations in common usage in transport modeling are seen to be questionable. For example, consider the concept of a friction factor where bed stress is taken to be proportional to the square of the magnitude of the velocity, independent of the sign of the velocity (e.g., Jensen et al., 1989). Our work has shown that such a formalism which has been adopted directly from steady flow conditions is incorrect. Similarly, any type of suspended load modeling which attempts to predict turbulent flow characteristics and therefore the suspended load (e.g., Bakker, 1974; Ribberink & Al-Salem, 1994) without considering the different stresses and kinetic energy distributions associated with crest-trough flow asymmetries could experience serious difficulty. Our results show that boundary ventilation represents another degree of similitude that is lacking in most laboratory studies of nearshore sedimentary processes.

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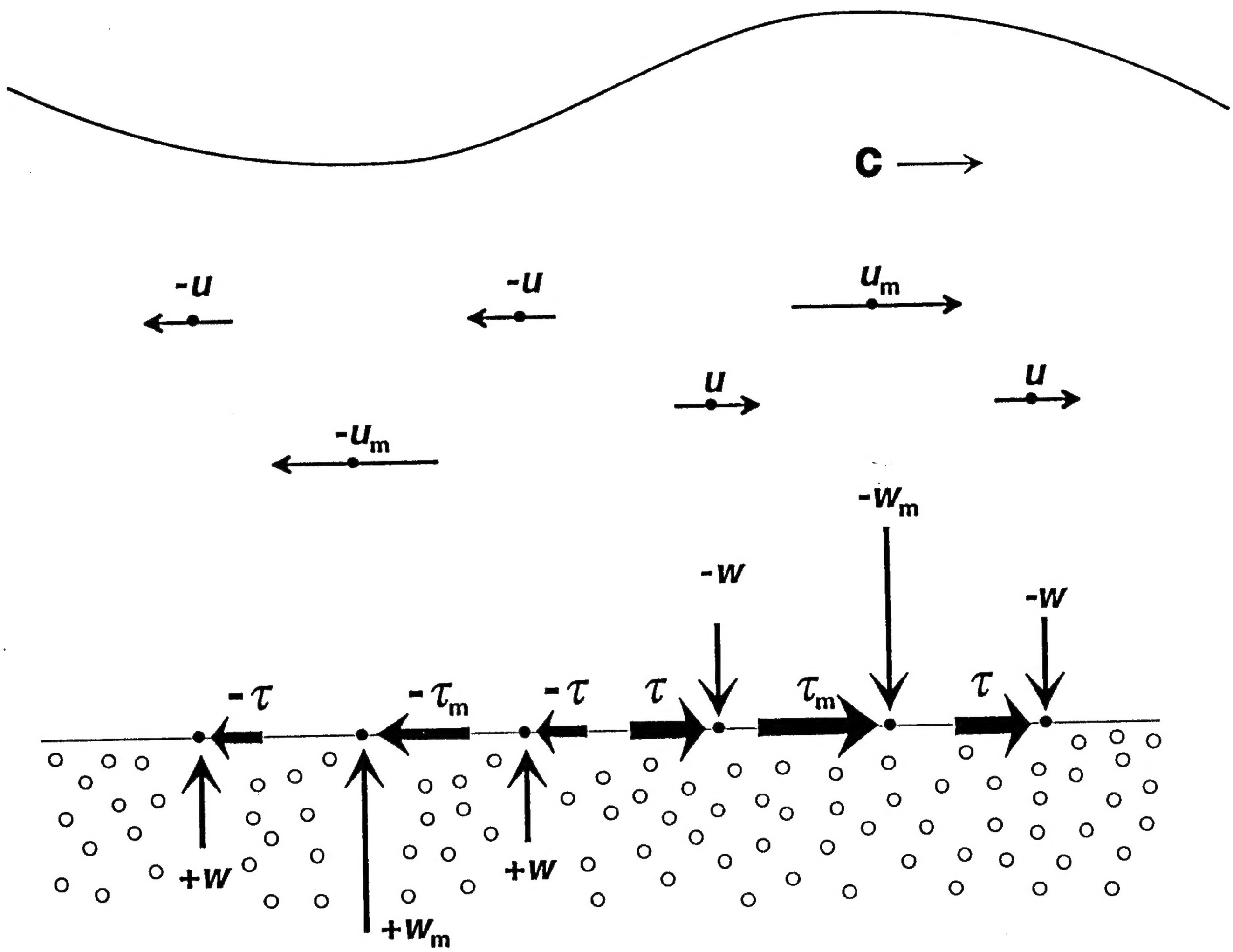

Figure 1. Definition sketch for stress asymmetry resulting from wave motion over ventilated porous beds.

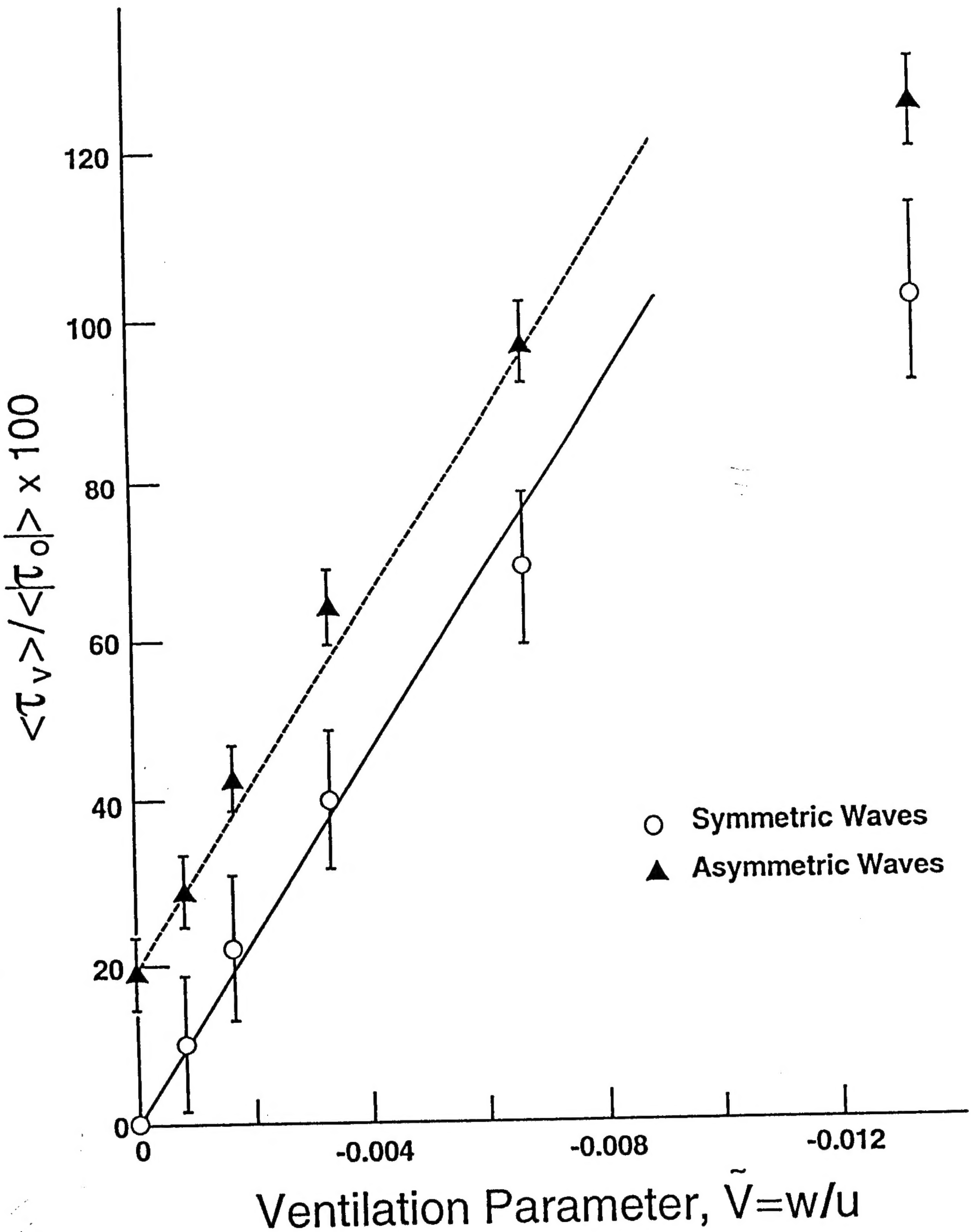

Figure 2. Stress asymmetry for ventilated symmetric and asymmetric waveforms. Brackets show 95% confidence intervals. [Data from Conley and Inman 1994].